Spatial Data Analysis as Decision Support Aimed at the Improvement of Agricultural Fertilization Strategies

Pundt, Hardy
Pleshkanovska, Roksolana
Harz University of Applied Sciences (HUAS)
Wernigerode, Germany
hpundt@hs-harz.de

Assmann, Denise
Böttcher, Falk
German Weather Service (DWD)
Leipzig, Germany
Denise.Assmann@dwd.de

Thiel, Enrico
Döhler, Johannes
Eißner, Florian
Kreuter, Thomas
Spott, Oliver
SKWPiesteritz (SKWP)
Cunnersdorf, Germany
Enrico.Thiel@skwp.de

Grunert, Michael
States Agency for Environment, Agriculture and Geology (LFULG)
Dresden, Germany
Michael.Grunert@smekul.sachsen.de

Abstract - Without fertilization, the sufficient provision of crops to feed the world population would not be possible. However, fertilization in agriculture also causes negative impacts. On the one hand, this concerns the environment e.g., by infusion of nitrate into the soil and groundwater. It is a challenge to guarantee both, a sufficient fertilization of soils, and the minimization of harmful emissions. The project "StaPrax-Regio", aims at an optimization of Nitrogen-(N)-fertilization strategies. It is well known that the interaction between weather, soil and the amount and time of fertilization are not independent from each other. Knowledge gaps still exist in a more detailed insight into the kind of interaction between the components, as well as the influence of specific parameters, such as precipitation and temperature, type, pH, cation exchange capacity of soils, and type, amount and time of fertilization. Therefore, meteorological and edaphic, as well as other factors must be taken into account when searching for a "good" fertilization practice at a specific site. Geographical Information Services (GIS) and Decision Support Systems (DSS) are adequate means to support data analysis and visualization, and finally the decision-making process on suitable fertilization strategies. The paper presents work-in-progress within the framework of a transdisciplinary research project of partners from industry, weather and geological services, and science.

Keywords. ***Fertilization, agriculture, soil data, weather data, GIS, spatial interpolation***

I. INTRODUCTION

Fertilizer nitrogen is mostly produced by applying the Haber-Bosch process [1]. Nitrogen (N) in the form of nitrate is a common pollutant in soils, surface and ground waters [2], [3]. Less than half of the more than 100 million tons of fertilizer N currently consumed yearly by agriculture is assimilated into the aboveground biomass of crops. While some fertilizer N will also be recovered by roots, much of the remainder is either leached or lost as environmentally harmful gas emissions [4]. Facing these facts, the goal of the StaPrax-Regio project is to achieve a better plant availability of N-fertilizers on the one hand, and to minimize harmful losses of N on the other. These goals were followed in other projects as well, however, StaPrax-Regio envisages a more comprehensive, data-driven approach thus integrating different information sources to achieve a holistic view on fertilization adapted as precise as possible to the local environmental conditions. The collaboration of different partners from practice, science and administration has been seen as a suitable way to achieve a multi-perspective, and therefore more sustainable, way to reach optimal fertilization strategies. Therefore, an industrial partner, producing N-fertilizers based on innovative methods (the consortiums leader), and administrations, such as weather and geological services, as well as a university, are collaborating within the StaPrax-Regio project.

Basic aspects and results of the research carried out in the first project year are presented, among others, in [5]. The main research question, how short-term meteorological events, as well as the specific soil conditions in different regions have influence on the capability of crop plants to absorb N, is still in the center of interest. New fertilizers include inhibitors that lead to longer availability of the fertilizer in the soil layers where roots of crops grow. In such a way they foster a better plant availability. Which consequences result from this in view of meteorological conditions, specific soil properties and fertilization practices? Facing questions like this, the partners work on different activities that are presented in an overview in Figure 1. The figure presents the steps that have to be gone within the project, from data collection and –processing to decision supporting maps. In the next section the input data sets, coming from different sources, and their analysis and visualisation are presented.

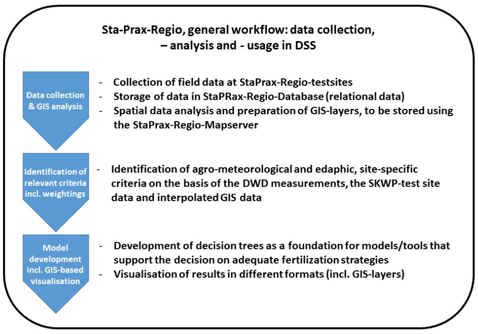

Figure 1. Data from agricultural test sites, meteorological stations and further sources have to be integrated to develop decision supporting models and tools [6]

The paper describes in the next section the current situation. Following, the data and the processing steps are explained that were carried out to achieve maps that are suitable to support decision making related to fertilization. The last section is aimed at mentioning further steps to be carried out during the next project year.

II. STATE OF THE ART

Fertilization in agriculture has ever been of large concern. Meanwhile, the subject has raised big attention: "(…) as our population grows to 10 billion people over the next few decades, we'll need even more nitrogen fertilizer. So, we find ourselves in a precarious situation: We need nitrogen for a healthy and growing population, but we're having a devastating effect on the environment by producing and using it." [7]. Much research is done concerning precision farming aiming at minimizing the amount of fertilizers used in agriculture. However, other attempts are on the side of the fertilizers themselves. An example is the stabilization with urease and nitrification inhibitors. This should lead to higher nitrogen efficiency and, as a follow-up, more environmental protection in agriculture. The urease inhibitor protects the urea from converting too quickly and also against ammonia losses. In addition to preventing N-losses, the subsequent nitrification inhibition leads to ammonium based plant nutrition, with adequate nitrate dispensation being assured at all times [15]. However, the dependence of fertilizing with such products from weather and soil conditions is obviously an important factor in successful fertilization strategies. Therefore, research attempts must proceed while taking into account more accurately all factors that play a role: meteorological and edaphic parameters, the various fertilizer alternatives, as well as further criteria [5], [8], [15]. Such a more holistic approach has been considered not sufficiently in the past. The purpose of the article is to inform about the methods and first results created during the still running project StaPrax-Regio.

III. PROCESSING DATA, THUS PREPARING THEM FOR DECISION SUPPORT

A. Data acquisition and spatial analysis

Apart from official websites that provide spatial data, the partners Stickstoffwerke Piesteritz (SKWP), German Weather Service (DWD), and the States Agency for Environment, Agriculture and Geology of Saxony (LfULG) collect data at many sites throughout the country. The DWD carries out measurements at 67 different sites in all relevant landscape types of Germany, whereas SKWP collects data from 85 test sites. The States Agency provides foremost soil data, as well as data from own test sites.

In general, this data is point-based. Figure 2 shows an example of the results of the usage of different fertilizer combinations at one test site. The bars represent the results that have been measured at one and the same site while using varying quantities of different fertilizers (see abscissa) [9]. Such data have to be investigated in relationship to, among others, weather-dependent data [10], e.g., soil humidity (Figure 3).

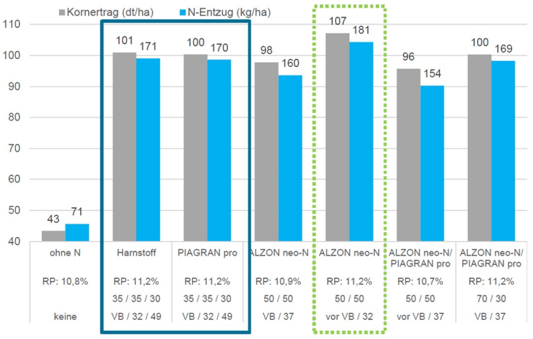

Figure 2. Exemplary, point-related results of fertilizer usage at a StaPrax-Regio-test site (Kornertrag = Grain yield; N-Entzug = Nitrogen removal) [9]

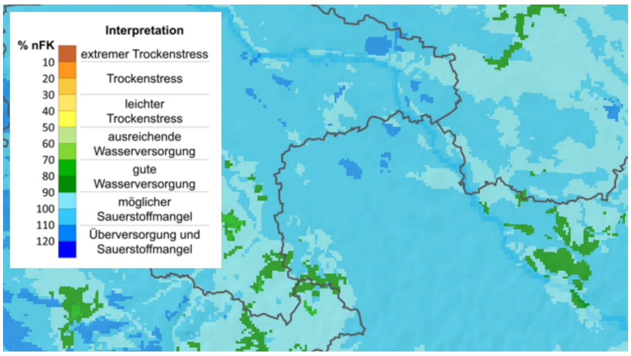

Figure 3. Interpolated soil humidity in 10cm depth [10]

For the provision of relevant data, the StaPrax-Regio MapServer has been implemented. The MapServer has been specifically configured for the StaPrax-Regio project and is based on a QGIS-Web-Client installation. It enables to publish GIS projects as OGC-compatible Web Map Services (WMS), Web Feature Services (WFS) or Web Coverage Services (WCS), and other formats. An adaptation of coordinate systems is easily possible and in such a way QGIS has been considered as an adequate and open-source solution for collecting, administering, analyzing and visualizing StaPrax-Regio related results. QGIS provides additionally functionalities and software extensions for spatial interpolation purposes. In such a way, the GIS tool includes important services to visualize, but foremost to modify the basic datasets and calculate area-wide layers which again can be overlaid with further relevant data. Concerning data quality, it can be stated that the positional accuracy is good enough for project purposes. The soil data relies on official data sources and the weather data are coming from the states weather service. All test sites that produce data on different fertilization strategies used are working on an approach that is acknowledged widely. Statistics based on the data applied in StaPrax-Regio are therefore robust and reliable.

B. Interpolation workflow

Most of the data acquired in StaPrax-Regio is point-related. The production of area-related information requires a suitable interpolation approach. A basic question to be answered here is the basic pattern in which the point data is provided [11]. Generally, there are three basic patterns in which such point data can occur, randomly (a), regularly (b) and clustered (c) (Figure 4).

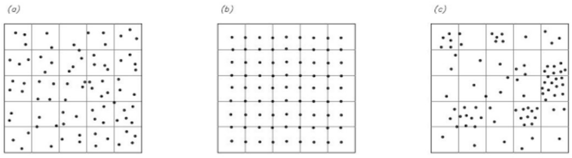

Figure 4: Possible patterns of point measurements [11]

For StaPrax-Regio, the data occur in a way that might be settled between (a) and (c). Distances between points vary as well as the number of points at different sites. These are spread over the whole country, however, different landscape types are represented through the test sites, the meteorological stations and the soil information. To achieve comparable results, an interpolation algorithm such as ordinary Kriging seems to be suitable to be used to generate area-related information on the various point-measured data. As mentioned before, the data used within the project are supposed to be reliable and therefore the interpolation results seem to be applicable for the overlay of interpolated and other spatial layers. Based on this assumption, the interpolation process is currently carried out on the usage of the software SmartMap, a QGIS extension. It provides, among others, the Kriging interpolation method [12]. Briefly summarized, the method relies on the semi - variogram which quantifies autocorrelation between the variance of data pairs and distance. At a certain distance autocorrelation becomes independent and this stage indicates that there is no longer any spatial relationship between the closeness of the data points. This makes Kriging to suitable linear, unbiased predictors under mild data conditions, thus proving to be a good method to interpolate spatial information [13]. Due to the irregular network of sampling points, the weather stations as well as the StaPrax-Regio test sampling sites (see section III.A and Figure 4), Kriging seems to be an adequate method, thus excluding non-relevant measurements, and having significant advantages concerning the given datasets and goal settings. Of course there are other interpolation approaches. It depends from the further project process if these should be tested and compared to the results achieved so far. Additionally, questions of isotropy and stationarity should be considered more sophisticatedly because edaphic and meteorological data might show differences here. Figure 5 presents the interpolation workflow as it is currently realized [14].

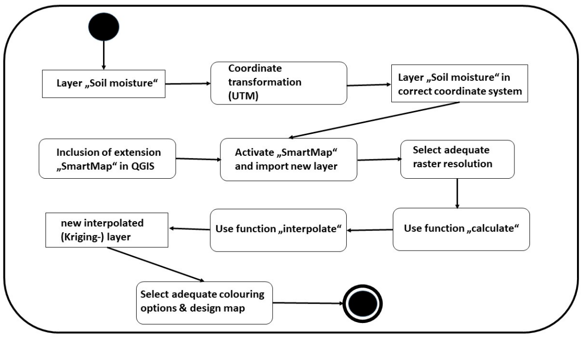

Figure 5. Exemplary GIS-based interpolation workflow [14]

C. Inclusion of processed data into decision-making procedures

Based on interpolated data, a "classic" GIS-overlay with further data layers can be performed which leads to new insights into local conditions (Figure 6):

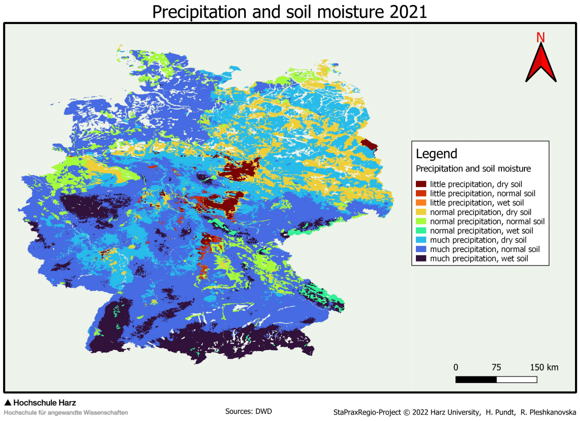

Figure 6. Overlay of previously interpolated data on soil humidity and precipitation [14]

The integration of the data from test sites, weather and edaphic information, including newly generated layers resulting from spatial analysis, will lead to spatial patterns which can help to improve decision-making on suitable fertilization strategies, especially envisaging a better uptake of fertilizers through crops under site-specific conditions [15]. This should have positive effects for the environment due to less emissions into the air, the (ground)water and the soil.

IV. CONCLUSIONS

The StaPrax-Regio-Mapserver provides basic spatial data layers, as well as analysis results, currently mainly based on classic methods such as spatial interpolation and overlay. However, the web-based system allows to explore the data in a multi-contextual view. This comes close to the insight that fertilization strategies should not consider only few factors, but the interaction between elements such as weather events, soil and landscape conditions, type of fertilizer and possibly machining technology. The overall project goal of such a holistic perspective on fertilization is to achieve more sustainable decisions instead of losing important information that can possibly, but not necessarily, play an important role [9].

After data collection at the test sites and the achievement of first results from analysis, the interpretation of such results is on the research agenda. Having defined procedures of how to prepare data for further analytical steps the project consortium will discuss adequate decision-making procedures. This requires differentiated thinking about the role each component plays and whether the various parameters can be handled uniquely or whether they have to be weighted in some manner. An efficient decision support will only occur when the spatial data layers become a helpful means to support farmers, agricultural consultants, and other decision makers. They should have helpful means to decide on a broad, comprehensive, and objective basis on a fertilization strategy that takes into account explicitly the edaphic and climatic particularities that vary from site to site. The definition of decision trees can help here [16]. This is also the basis for a DSS that is under development (web-BESyD [17]) at one StaPrax-Regio partner. It includes specific spatial datasets based on decision trees that are currently under critical review within the StaPrax-Regio consortium.

One important result is that defined different amounts of fertilizer combinations, including those with inhibitors, which were analyzed at all test sites, lead to different crop yields. This is due to the different edaphic and meteorological situations at the test sites. However, the overall goal is to answer the question whether spatial patterns can be identified, that allow to define recommendations, at best standardized fertilization strategies that are based on the data-driven research as it is carried out in StaPrax-Regio. Such strategies, taking into account explicitly all relevant components that play a role for crop growth and health, should be more environment-friendly, less expensive and therefore sustainable [5], [15], [18]. The first two project years gave important insights based on comprehensive spatial data form the test-sites that cover different landscapes throughout the country, thus enabling the integrated view on the situations. The next steps to be carried out will show, if such spatial patterns exist and if they deliver a basis to define best practices.

ACKNOWLEDGMENTS

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